3.1 De oceaanbodem en de diepzee

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6.1 How the Second World War changed marine science

The shore is where people first fall in love with the sea. Coastal environments are some of the most studied marine environments worldwide, because they are easily accessible for scientists interested in the biodiversity of our oceans. Conducting studies and experiments on the coast is easy because you need no special equipment to get there and it is easy to return to the same spot to repeat surveys. A love of the coast is not restricted to scientists, however: whenever you spend a sunny day relaxing at the beach, you are enjoying a small piece of the littoral zone.

While scientists may have started by studying the sea from dry land, they soon wanted to know what lies below the large bodies of water that dominate our planet. Images of the Kraken and other sea monsters swam through the minds of many sailors for thousands of years, as they wondered what really lay below the keels of their ships.

Unfortunately for those seafarers, it was not until the 20th century that technology became advanced enough to allow us to see what lies on the seabed, even though the technology used to explore the seabed was actually designed with another purpose in mind.

During the Second World War, many countries needed to be able to detect enemy submarines in the ocean. New technology was needed to make this possible, and that is why SONAR (an acronym for **so**und **n**avigation **a**nd **r**anging) was invented. SONAR enables scientists to map the ocean floor, and some amazing discoveries have been made using SONAR data. Instead of flat, barren plains stretching from shore to shore, scientists found mountain ranges dividing oceans in half and trenches sinking deeper than the highest mountains. This technology, followed quickly by SCUBA (**s**elf-**c**ontained **u**nderwater **b**reathing **a**pparatus), has been used for studies throughout the oceans, changing preconceived notions and providing evidence for new theories about the geology of our planet.

6.2 Plate tectonics

The history behind the theory of plate tectonics

In 1912, a German scientist named Alfred Wegener proposed an unusual theory regarding our planet to the geologists of his day. Wegener based his theory on evidence from multiple disciplines of science, such as geology and palaeontology. While looking at studies performed by other scientists, Wegener realised that identical fossilised plants and animals had been found on the coasts of different continents separated by oceans. When comparing geological structures (for example mountains) between continents, he found evidence that the rock layers in South Africa match those in Brazil. Between Europe and North America, he discovered that the structure of the Appalachian Mountains in the United States closely matches that of the mountains in the West Highlands of Scotland. Wegener then argued that the shape of the coastlines with matching geological features – South America and Africa, North America and Europe – fit together like pieces of a jigsaw puzzle. Using these observations, Wegener developed his theory of **continental drift**. This theory claims that, more than 300 million years ago, all the continents on Earth were joined as a single landmass Wegener named Pangea. Over the course of millions of years, Pangea began to split and its pieces have been slowly moving further and further away from each other since then.

Unfortunately for Wegener, his theory was not well received. In spite of the evidence he presented, his peers were not convinced that continental drift was happening or had ever happened. This was partly because Wegener did not suggest a clear mechanism by which continents moved. He proposed continents ploughed through the oceanic crust as an iceberg moves through water. Other scientists pointed out that this would change the shape of the continents, refuting the evidence Wegener was relying on to support his theory. Scientists at the time insisted on the idea of non-moving continents with long-gone land bridges for animals and plants to cross. It was another 50 years before other scientists were able to discover enough evidence to determine what was really happening. This evidence led them to new discoveries in the fields of geology, morphology and ecology of the oceans.

KEY TERM

Continental drift: a theory supporting the possibility that continents are able to move over Earth's surface

KEY TERMS

Plate tectonics: the process where large sections ('plates') of the Earth's crust are in constant movement over the fluid mantle, causing earthquakes and volcanoes at the borders between the plates

Lithosphere: the outermost layer of the Earth's crust

Asthenosphere: a nearly liquid layer made of the uppermost part of the mantle

Mantle: a region of molten rock within the interior of the Earth, between the core and the crust

The theory of plate tectonics

In the 1960s, the continental drift theory was revised as new evidence came to light. The revised theory included a mechanism for how the continents were actually moving across the surface of our planet, a factor missing from Wegener's original theory. The new theory – the theory of **plate tectonics** – suggests that the outermost layer of the Earth's crust, the **lithosphere**, is made up of many different plates called tectonic plates. Each of these plates floats independently on the nearly liquid **asthenosphere**, a layer made of the uppermost part of the **mantle** (Figure 6.1).

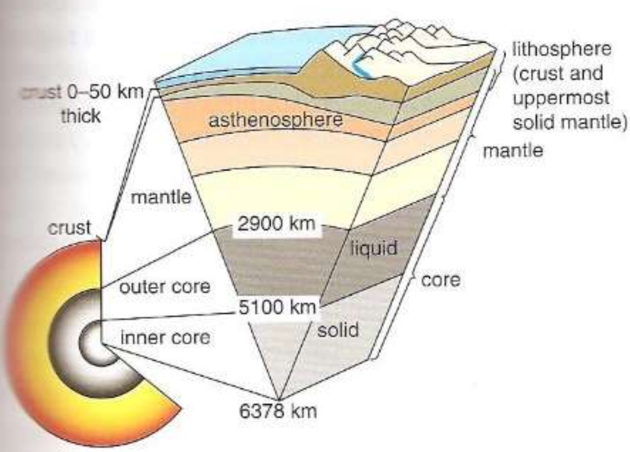

Figure 6.1. A diagram of the Earth's interior.

Evidence supporting the theory of plate tectonics

Seabed spreading

Many lines of evidence supporting plate tectonics have been discovered by scientists since the theory was first proposed. The concepts used by Wegener to support continental drift, of coastlines 'fitting' together and fossils being spread over multiple continents, also support the theory of plate tectonics. However, after the invention of SONAR, new evidence of plate boundaries came to light on the bottom of the ocean.

The data collected while looking for submarines showed mountains and trenches lining the edges of plate boundaries. These geological features created a clear map of where the tectonic plates line up. Marie Tharp, a geologist and oceanic cartographer, and her partner Bruce Heezen, a geologist, collaborated for 20 years to collect ocean floor mapping data in order to create an accurate, scientific map of the seabed. This map (Figure 6.2), called the World Ocean Floor, revolutionised Earth science after its publication in 1977, because of the prominent presence of the mid-ocean ridge. This map is responsible for convincing many scientists to accept the theory of plate tectonics and seabed spreading.

Figure 6.2. The World Ocean Floor by Marie Tharp and Bruce C. Heezen.

Magnetic polarity reversal

More evidence supporting the theory of plate tectonics was discovered after the Second World War had ended. Scientists began studying magnetism on the ocean floor using magnetometers created to locate submarines during the war, as SONAR had been. The evidence they found surprised them. The magnetic field of the ocean floor was laid out in alternating stripes of normal polarity and reversed polarity.

The fact that the ocean floor was magnetic was not the surprise. Sailors had known for more than 100 years that the basaltic rocks lining the ocean floor were magnetic. It was the striped pattern that was unexpected. Further research showed that the striped pattern had an origin around the mid-ocean ridges, where the crust is weakest and magma often pushes through (Figure 6.3). This magma held the explanation.

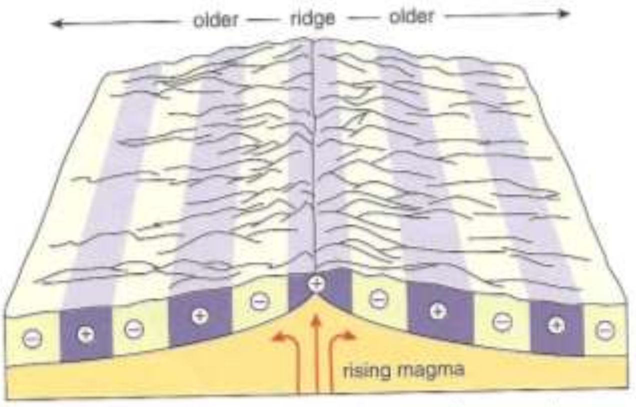

Figure 6.3. Seabed spreading and magnetic reversal.

Basaltic rocks, the type commonly found on the seabed, are an example of an igneous rock. Igneous rocks are created when molten magma from a volcanic eruption cools and hardens. Within igneous rocks is a naturally magnetic iron material called magnetite, which is why basalt is magnetic. When molten magma first reaches the Earth's surface, the particles of magnetite within it align with the Earth's magnetic field. Once the magma begins to harden, the magnetite is locked in place, holding information about the Earth's magnetic field at the time the rock was formed. Scientists have found that the Earth's magnetic field reverses on average every 250 000 years, changing magnetic north to magnetic south. This information, when applied to the ocean floor, provides unique evidence in support of the theory of plate tectonics.

At divergent boundaries, where mid-ocean ridges form, scientists now know the seabed is spreading because of magma rising from the mantle and hardening into igneous rocks. When the magnetic properties of the rocks at these boundaries were measured, scientists confirmed that the rocks lay in alternating stripes of magnetic polarity radiating away from the boundary in parallel lines. These stripes differed in width based on the length of time between each reversal, providing the strongest evidence in support of seabed spreading and plate tectonics.

SELF-ASSESSMENT QUESTIONS

1 Compare the theory of continental drift with the theory of plate tectonics.

2 List the major lines of evidence for the theory of plate tectonics.

6.3 Plate boundaries

In order for lithospheric (tectonic) plates to move, the asthenosphere must be moving as well. This movement is caused by **convection currents** within the mantle. Convection currents happen when the molten rock of the mantle moves because of density changes in the rock caused by temperature differences. In other words, as the molten rock is heated, it becomes less dense as the molecules spread out. The less dense rock moves upwards in the mantle towards the crust in order to float on top of the denser rock. Then, as the rock begins to cool, it begins to sink towards the warmer core. This forms a circular cell of flowing molten rock capable of moving the lithospheric plate lying on top of it. Because the plates are heavy and the convection currents in the asthenosphere move so slowly, the plates move only 2–5 cm year^{-1}. However, even this small movement causes the plates to meet and form three types of boundary: convergent, divergent and transform. Each boundary type has identifiable characteristics and geological features (Figure 6.4).

KEY TERMS

Convection current: the movement of fluids or air based on density differences caused by differing temperature

Convergent boundary: when two or more tectonic plates come together

Subduction: the process where one lithospheric plate slides below another at a convergent plate boundary

Trench: a long, narrow and deep depression on the ocean floor with relatively steep sides, caused by convergent plate boundaries

Volcano: a mountain or hill with a crater or vent through which lava, rock fragments, hot vapour and gas are being forced from the Earth's crust

Earthquake: a sudden release of energy inside the Earth that creates seismic waves usually caused by movement of tectonic plates or volcanic activity

Tsunami: a seismic sea wave created by an underwater earthquake or volcanic event, not noticeable in the open ocean but building to great heights in shallow water

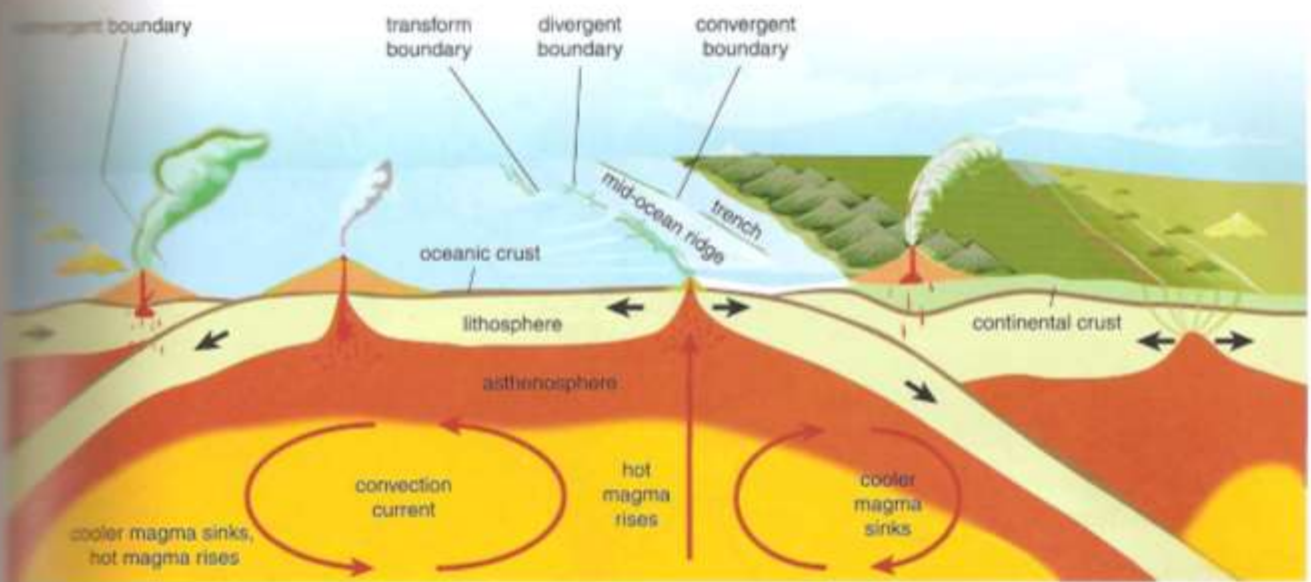

Figure 6.4. Visual representation of plate boundaries and their features.

Convergent boundaries and their features

Convergent boundaries form when two tectonic plates are moving towards each other. These boundaries form **subduction** zones where one plate, typically a denser oceanic plate, slides underneath the other, less dense, continental plate. These areas are known as destructive zones. This is because, as the denser oceanic plate slides below the continental plate, it is destroyed by the heat of the asthenosphere and returns to the molten mantle. Common features along subduction zones are **trenches**, **volcanoes**, **earthquakes** and **tsunamis**.

Trenches are long, narrow, deep canyons in the seabed. Trenches only occur at subduction zones within convergent boundaries. The deepest part of the ocean, Challenger Deep, exists within the Marianas Trench in the western Pacific Ocean. Challenger Deep is 11 033 m deep, which is deeper than Mount Everest is tall (8848 m).

A volcano is formed when an opening in the Earth's crust allows gases and molten rock to escape from the mantle. Volcanoes that rise above sea-level form new islands like those in the Hawaiian and Philippines archipelagos. However, many volcanoes are located under the ocean's surface, creating new seabed when the magma cools after erupting. Of these underwater volcanoes, most lie along the convergent plate boundaries surrounding the Pacific Ocean. Together, they create what is known as the Ring of Fire (Figure 6.5). The areas that border the Ring of Fire are hotspots for volcanic and seismic activity. Volcanoes can also be found at divergent boundaries and areas where the crust is very thin.

Earthquakes occur after there has been a sudden release of energy from the movement of the Earth's crust. When two plates are moving past each other, at either a convergent or transform boundary, they may get stuck. When this happens, the pressure for them to move builds and builds until movement finally happens, releasing stored potential energy in a sudden burst. This burst of energy releases seismic waves that move through the lithosphere making everything on top of the crust shake. Volcanoes are also capable of causing an earthquake when they release enormous amounts of energy during an eruption.

Sudden releases of energy on the seabed, either through an earthquake or a volcanic eruption, can lead to tsunamis. Tsunamis are long-wavelength, high-energy waves created by seismic activity. When an earthquake releases its stored energy on the seabed, it moves all the water lying above. The water holds on to this energy and moves very quickly but unnoticeably through deep ocean water. However, as the tsunami reaches shallow, coastal waters, the wave slows down and grows exponentially in height. These large, high-energy waves can be incredibly destructive. Tsunamis are sometimes called 'tidal waves' but this is inaccurate because the tides have nothing to do with the creation of tsunamis.

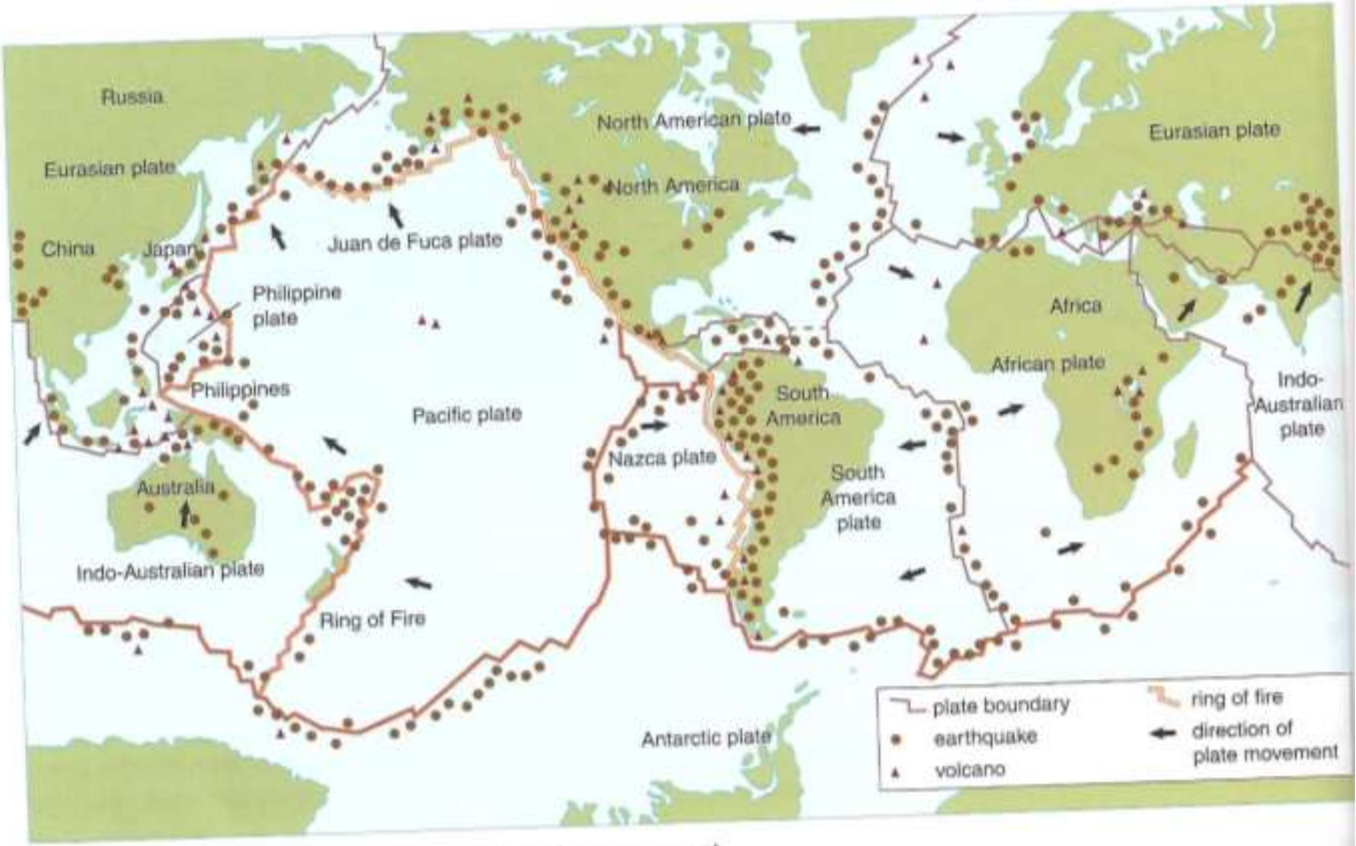

Figure 6.5. The Pacific Ring of Fire with tectonic plate movement.

Divergent boundaries and their features

Divergent boundaries are areas where the tectonic plates are moving away from each other and allowing molten magma from the mantle to push through to the crust. These areas are considered to be constructive zones. As the magma, driven by convection currents, pushes through the opening in the crust, it spreads out and solidifies in the cold ocean waters at the bottom of the sea. The new rocks created through this process eventually build up and form underwater mountain ranges called **mid-ocean ridges**. As these mid-ocean ridges continue to build new crust, there is an eventual movement away from the divergent boundary, causing seabed spreading. Seabed spreading helps to move tectonic plates towards convergent boundaries on the opposite side of the planet. This process, over the course of millions of years, is responsible for a shrinking Pacific Ocean and growing Atlantic Ocean. Located within these mid-ocean ridges are volcanoes and hydrothermal vents, which are discussed in further detail later in this chapter.

KEY TERMS

Divergent boundary: where two tectonic plates are moving away from each other

Mid-ocean ridge: a mountain range with a central valley on an ocean floor at the boundary between two diverging tectonic plates, where new crust forms from upwelling magma

Transform boundary: when two plates are moving in an antiparallel direction, creating friction between them

Abyssal plain: a flat, sandy region of the ocean floor found between trenches and the continental rise

Transform boundaries and their features

Transform boundaries are areas where two plates slide laterally next to each other. No crust is created or destroyed at transform boundaries. However, transform boundaries are areas of great seismic activity. The increased friction between plates at these boundaries causes small cracks called faults to form. The pressure that builds up in these fault lines can lead to earthquake and tsunamis. The most common ocean feature found

...transform boundaries are **abyssal plains**, which are ...ssed in the section on the seabed.

...ASSESSMENT QUESTIONS

3 Describe how tsunamis are formed.
4 How are divergent and convergent boundaries related to the rock cycle?

...TERMS

Hydrothermal vent: an area where cold ocean water that has seeped into the Earth's crust is superheated by underlying magma and forced through vents in the ocean floor

Figure 6.6. A hydrothermal vent along the Juan de Fuca Ridge in the northern Pacific Ocean.

6.4 Hydrothermal vents

Hydrothermal vent systems were discovered in 1977 along the Galapagos Rift in the Pacific Ocean by scientists from Woods Hole Oceanographic Institute (WHOI) using the deep sea submersible *Alvin*. Hydrothermal vents (Figure 6.6) occur in deep ocean water, usually 2000 m or more below sea-level, within mid-ocean ridge systems. At this depth, the pressure is over 200 atmospheres and there is no light. These are unique circumstances for the development of an ecosystem.

Hydrothermal vents are formed when cold ocean water seeps through cracks in the thin crust surrounding divergent boundaries (Figure 6.7). As the water moves through the crust to an area directly over a magma chamber, it dissolves minerals (for example iron, copper and zinc sulfides) from the rocks, turning it black. Once heated by the magma, the water reaches temperatures well over 100 °C but never boils because of the extreme pressure in the region. This superheated water then escapes the crust through a fissure above.

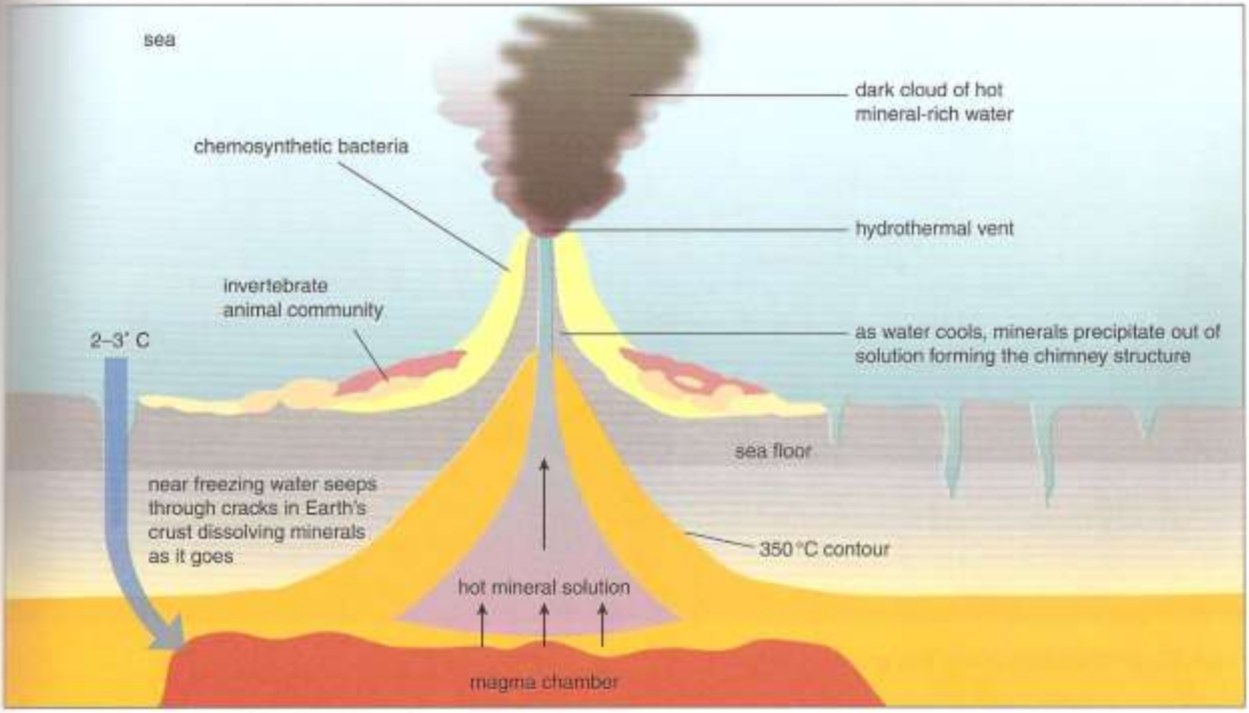

Figure 6.7. Formation of a hydrothermal vent.

As the superheated water meets the near freezing water on the ocean floor it begins to cool. As the water cools, the minerals precipitate out of solution. This means the minerals form solids, which settle near the fissure, piling on top of each other. This forms a chimney, or vent, for the superheated water that can be up to 60 m high. These hydrothermal vents release water at temperatures over 350 °C. They are often referred to as 'black smokers' because of the black smoke-like look the water has as it escapes from the chimney. The chemicals contained in the water are the basis for energy capture, chemosynthesis, in these dark waters (see Chapter 2).

SELF-ASSESSMENT QUESTIONS

5 Why do you think it took until 1977 for scientists to discover hydrothermal vents?

6 Would you describe this environment as extreme? Why or why not?

6.5 Seabed

The ocean floor is divided into specific regions based on physical structure and location. The **continental margin** comprises approximately 28% of the ocean floor. This region of the ocean floor divides the thin, but dense, oceanic crust from the thicker, less dense, continental crust located at the edge of continents. Within the continental margin are three distinct zones (Figure 6.8).

- The **continental shelf** is the flat, shallow area extending from the shore to the continental slope. This area tends to be featureless because of the deposition of sediments as a result of wave action. The average width of continental shelves is 70 km, but they range from 20 km to 1500 km. The widest continental shelves happen in areas where there is little tectonic action taking place.
- The **continental slope** begins where the continental shelf ends. This region is a fairly steep area of the

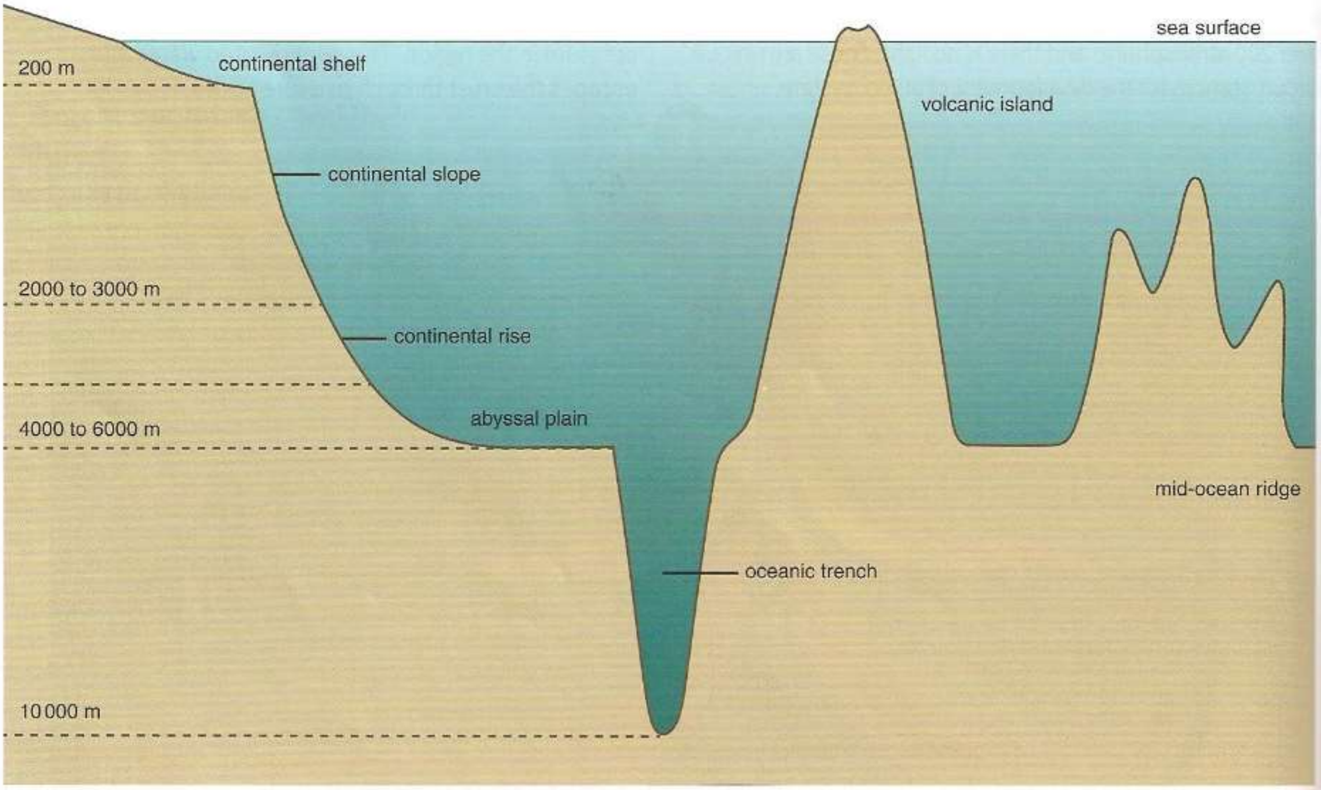

Figure 6.8. Diagram of the seabed, not drawn to scale.

seabed that descends into the ocean basins. This area is even steeper when located near a convergent boundary because of the presence of trenches.

- The **continental rise** is a narrow edge to the continental slope connecting the continental slope to the seabed.

KEY TERMS

Continental margin: the submerged area next to a continent, which includes the continental shelf, continental slope and continental rise

Continental shelf: a gently sloping surface that extends from the low tide line to the continental slope, typically where a great deal of sand deposits

Continental slope: a relatively steep sloping surface between the continental shelf and the continental rise

Continental rise: a gently sloping surface at the base of the continental slope where sand deposits

Leading from the continental rise are incredibly flat areas of the ocean floor called abyssal plains. These areas are located at depths between 3000 and 6000 m below sea-level and can typically be found between the continental rise and a mid-ocean ridge. Abyssal plains make up more than 50% of the Earth's total surface area. This flat plain is formed when the uneven, rocky surface of the seabed is slowly covered in sand and decomposing organic matter that sinks to the bottom of the ocean.

Opdracht bij les 3.1

- Case study: ‘De levenscyclus van de diepzee zeeduivel’ OF zoek een artikel over het gevolg van zeebevingen op mariene dieren en vat dit kort samen

Les 3.1 - De levenscyclus van de diepzee zeeduivel

Het leven in de donkere, diepere delen van de oceaan is niet makkelijk. De druk van het water is extreem hoog, er is geen licht en erg weinig leven. Vissen die op grote diepte leven komen maar zelden prooien en soortgenoten tegen, dus wanneer die gebeurt moeten deze ontmoetingen succesvol zijn.

Sommige vormen van de diepzee zeeduivel hebben zich aangepast aan deze omstandigheden door een erg ongewone levenscyclus te hebben. Het mannetje en het vrouwtje zijn zeer verschillend. De vrouwtjes zijn groot en zien er gevaarlijk uit met grote monden en tanden zodat voedsel makkelijk gevangen kan worden. Sommige soorten hebben een bioluminiscent aas waarmee ze andere vissen kunnen aantrekken. Als een maaltijd maar een keer per maand voorbij komt, is het belangrijk dat deze gevangen wordt. De vrouwtjes hebben ook grote eierstokken die grote hoeveelheden eitjes kunnen produceren.

Het mannetje is erg anders. Ze zijn klein en hebben een onderontwikkelde mond en verteringsstelsel. Hun kleine formaat betekent dat ze weinig energie nodig hebben om zich te bewegen, maar ze hebben wel een goed ontwikkeld reukorgaan en testikels. Deze kleine mannetjes kunnen chemische stoffen waarnemen die de vrouwtjes afscheiden en daarnaartoe zwemmen. Wanneer ze een vrouwtje tegen komen zetten ze zichzelf aan haar vast met hun mond en worden ze een parasiet.

Een verbinding van bloedvaten vormt zich tussen en vrouwtje en het mannetje waardoor hij onderdeel wordt van haar lichaam, gevoed door haar bloedtoevoer. Als hij eenmaal vast zit, blijft hij onderdeel van haar lichaam zolang het vrouwtje leeft, in principe is hij een sperma producerend orgaan dat altijd in de buurt van het vrouwtje is. Vrouwelijke diepzee zeeduivels hebben vaak meerdere parasitische mannetjes aan zich vast zitten.

1. Waarom is het mannetje klein en heeft hij een onderontwikkeld verteringsstelsel?

2. Waarom is het belangrijk dat het vrouwtje voedsel lokt en een goed ontwikkelde mond heeft?

3. Waarom is deze levenscyclus een goede strategie in de diepzee?

4. Wat is het voordeel voor het vrouwtje om zich met meerdere mannetjes te verbinden?

5. Is parasitisme de juiste benaming voor deze relatie? Waarom wel of niet?